

The University of Chicago

COMBINED EFFECTS OF
POTASSIUM SUPPLY AND GROWTH
SUBSTANCES ON PLANT
DEVELOPMENT

A DISSERTATION SUBMITTED TO THE
FACULTY OF THE DIVISION OF THE
BIOLOGICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF BOTANY

1941

By
HORTON M. LAUDE

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COMBINED EFFECTS OF POTASSIUM SUPPLY AND GROWTH SUBSTANCES ON PLANT DEVELOPMENT¹

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY 529

HORTON M. LAUDE

(WITH SIX FIGURES)

Introduction

The reported dry-weight determinations of plants treated with growth-regulating substances have indicated both losses and gains associated with such treatment. GRACE (4), HWANG and PEARSE (6), McROSTIE, HOPKINS, and GRACE (8), MITCHELL and HAMNER (9), and THIMANN and LANE (17) have all reported increased dry weight of various plants owing to such treatments. PEARSE (12, 13) found the dry weight of leaf and root decreased while that of stem and petiole increased in tomatoes, yet the total dry weight did not increase. TEMPLEMAN (16), using white mustard and barley, reported only significant depressing effects from growth substance treatment and no stimulation of top or root weights.

The combined effects of variation in nutrient supply and growth-regulating substances have been studied in a few instances. Nutrition as it affects the production of growth substance within the plant has been investigated by AVERY, BURKHOLDER, and CREIGHTON (1, 2) and by SKOOG (15). Nutritional levels and growth-substance treatments in relation to root development and carbohydrate and nitrogen distribution within the plant have been reported by SMITH, NASH, and DAVIS (14). EATON (3) suggested the ability of externally-applied indoleacetic acid partially to replace boron as an essential element. SKOOG (15) noted that applied indoleacetic acid may enhance the utilization of zinc.

The investigation here reported deals with the effects—at different levels of potassium—of growth substance supplied in the nutrient medium to sand cultures of kidney bean.

Material and methods

Red kidney bean, *Phaseolus vulgaris*, was grown in white quartz sand in 4-inch glazed pots. Before planting the seed the sand was thoroughly wet with distilled water and given one application of minus potassium nutrient. This first addition of nutrient was necessary to insure uniform and vigorous plants soon after emer-

¹ This work was aided in part by a grant from the Dr. Wallace C. and Clara A. Abbott Memorial Fund of the University of Chicago. The assistance of Dr. C. L. HAMNER in the experiment with naphthalene acetamide is appreciated.

gence; without it the plants did not properly expand their first foliage leaves. Four selected seeds were planted at uniform depth in each pot. As soon as the heart-shaped leaves were expanded, the plants were thinned to two per pot. Seed coats and ungerminated seeds were removed.

Five nutrient solutions, designated as minus K, $1/18$ K, $3/9$ K, $9/9$ K, and $18/9$ K, were prepared in the following manner. The amount of 0.5M stock solution of the reagent quality salts used for every liter of nutrient solution is listed. Distilled water was employed in all solutions.

The minus K nutrient solution consisted of 12 cc. of 0.5M $\text{Ca}(\text{NO}_3)_2$, 9 cc. of 0.5M MgSO_4 , and 9 cc. of 0.5M NaH_2PO_4 per liter. The $1/18$ K nutrient solution contained 12 cc. of 0.5M $\text{Ca}(\text{NO}_3)_2$, 9 cc. of 0.5M MgSO_4 , 0.5 cc. of 0.5M KH_2PO_4 , and 8.5 cc. of 0.5M NaH_2PO_4 per liter. The $3/9$ K nutrient solution consisted of 12 cc. of 0.5M $\text{Ca}(\text{NO}_3)_2$, 9 cc. of 0.5M MgSO_4 , 3 cc. of 0.5M KH_2PO_4 , and 6 cc. of 0.5M NaH_2PO_4 per liter. The $9/9$ K nutrient solution employed 12 cc. of 0.5M $\text{Ca}(\text{NO}_3)_2$, 9 cc. of 0.5M MgSO_4 , and 9 cc. of 0.5M KH_2PO_4 per liter. The $18/9$ K nutrient solution consisted of 12 cc. of 0.5M $\text{Ca}(\text{NO}_3)_2$, 9 cc. of 0.5M MgSO_4 , 9 cc. of 0.5M KH_2PO_4 , and 9 cc. of 0.5M KCl per liter. A somewhat higher osmotic concentration resulted in the $18/9$ K level owing to the addition of KCl to the other salts. All nutrient solutions uniformly contained iron, boron, manganese, and zinc at 0.5 p.p.m. and copper at 0.125 p.p.m.

Indoleacetic acid (Merck and Company) and alpha naphthalene acetamide (American Chemical Paint Company) were employed as the growth substances. They were used individually in series of concentrations ranging from 10^{-4} to 10^{-11} by multiples of ten at the several levels of nutrition. Fresh stock solutions of the growth substances were prepared for each watering. The proper amount of these solutions was mixed with the nutrient to give the desired concentration immediately before watering the plants. Applications were given three times a week between the first treatment, 10 days after planting, and harvest at the flowering stage. The volume of nutrient solution was increased as the plants matured, so that there was always a slight run off through the pot drain after each application.

Fresh and dry weights were taken for the tops, and dry weights for the roots. The roots were freed of sand by washing over a screen, dipping in saturated salt water, and rinsing in clear water. The material was dried for 24 hours in a well-ventilated draft oven at 80°C . Samples removed from the oven were kept in desiccators until weighed.

The experiments were designed on a factorial system, with treatments randomized within blocks; and an analysis of variance (11) was used to establish the significant points regarding top dry weight, root dry weight, and total plant dry weight.

Investigation

INDOLEACETIC ACID

EXPERIMENT I.—This ran from October 10 to November 7, 1940. During this period 60 per cent of the days were sunny and growing conditions were good. Plants reached the flowering stage in 28 days after planting the seed. Nutrient levels of minus K, 1/18 K, 3/9 K, and 9/9 K were used. An analysis of variance of the dry weight of the tops indicated significant increases at indoleacetic-acid concentrations near 10^{-9} over plants receiving the same 9/9 K nutrient but without the growth substance. The differences in response between plants receiving and those not receiving the acid at the 3/9 K, 1/18 K, and minus K levels were not significant. There was a tendency for dry weight of roots to increase with increasing concentrations of the growth substance and for dry weight of the tops to decrease at the higher concentrations. Also a definite decrease in succulence was associated with decreasing amounts of potassium.

EXPERIMENT II.—A more extensive experiment was designed having six blocks, within each of which thirty-one treatments were randomized (table 1). There were eight plants to a treatment in each block, and thus forty-eight plants to a treatment in the entire experiment. The results of this experiment illustrate those of the first as well.

This experiment was carried on between January 24 and February 25, 1941. Only 40 per cent of the days were sunny, there being less light than in the autumn. Thirty-two days were required for flowering. During this time ten applications of nutrient and growth substance were given. The greenhouse temperature averaged 70° F., and the average relative humidity ranged from 60 to 70 per cent.

No epinastic response was noted, even at the 10^{-4} and 10^{-5} concentrations after applications. This was in contrast to phosphorus-deficient and boron-deficient bean plants grown at the same time and receiving the same indoleacetic-acid concentrations, for these showed definite epinastic curvatures of the primary leaves. The first trifoliate leaves of the plants at the 10^{-4} concentration were very pale green compared with the 10^{-5} or any other treatment. This partial chlorosis persisted in the second and third trifoliate leaves as they appeared. Likewise the first obvious signs of stunting appeared at this concentration. By the eighteenth day after planting (twelfth after emergence), height differences were marked enough to distinguish clearly between the taller plants of the upper two potassium levels and the shorter plants of the lower two.

The first visible symptom of potassium deficiency appeared on the nineteenth day after planting in the minus K treatments. It required 6 additional days for this condition to become obvious in the 1/18 K plants. This first symptom was shown by the action of the pulvinus at the base of the primary leaf blade. Those

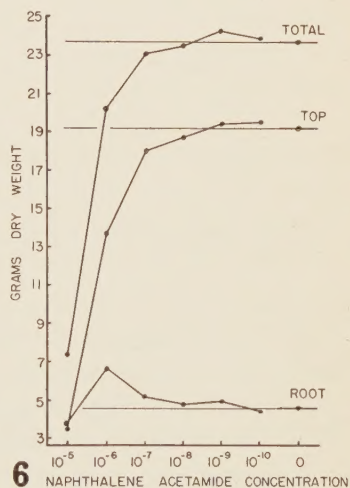
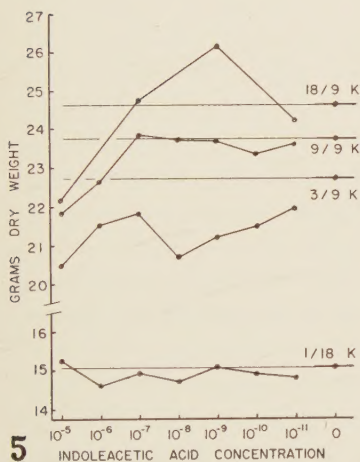
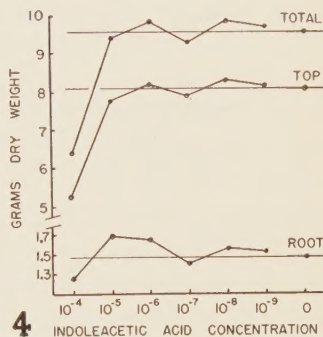
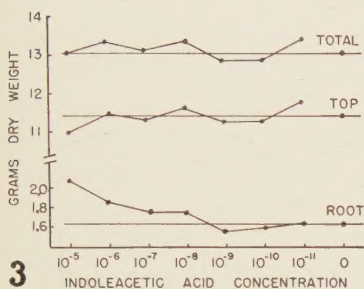
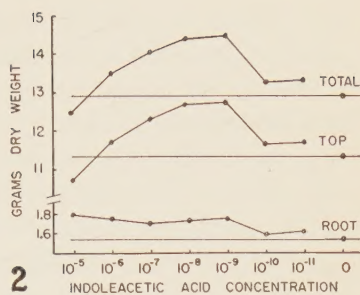
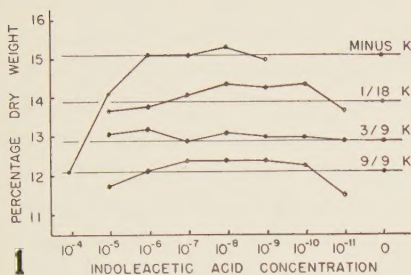
leaf blades which would a short time later exhibit the characteristic marginal chlorosis of deficiency would retain the nocturnal pendant position during the day. All others remained horizontal except at night. The early marginal yellowing of the deficient leaf blades was followed by more extensive chlorosis, until the entire leaf blade was chlorotic. The veins were the last portion so affected. By the time of harvest the primary leaves had begun to absciss and the first and even second trifoliate leaves were somewhat mottled with chlorotic areas.

By the twenty-seventh day after planting, flower buds were evident on all plants regardless of treatment. At harvest on the thirty-second day a few of these buds had commenced to open. Leaf size varied with concentration of growth substance supplied. The more stunted plants at the higher concentrations had considerably less leaf area than had those plants receiving a more favorable concentration. All plants, regardless of treatment, had at the same nutrition level the same total number of leaves.

The percentage dry weights for the bean tops are shown in figure 1. Although the range of the percentages is only slightly over 3.5 per cent, there does seem a clear-cut response to each nutritional level, and this response in a definite order. Succulence increases with increasing amounts of potassium. With the exception of the two highest concentrations of indoleacetic acid at minus K, all the points are well stratified. There seems little relationship between quantity of growth substance and percentage dry weight over the central range of the concentrations used. However, the rapid drop in percentage dry weight with the greatest amount of indoleacetic acid suggests that high concentrations may have a more measurable effect. Increases in succulence as a result of supplied growth substance have been reported, and it appears likely that they were associated with relatively high concentrations.

The dry-weight data of total plant, top, and root represent average weights for each treatment (table 1). An analysis of variance to establish the differences between these means necessary for significance at probabilities of 5 per cent and 1 per cent gave the following results. Mean differences are significant if greater than 1.00 gm. at 5 per cent and 1.32 gm. at 1 per cent probability for dry weight of total plant; 0.47 gm. at 5 per cent and 0.62 gm. at 1 per cent probability for dry weight of tops; and 0.22 gm. at 5 per cent and 0.29 gm. at 1 per cent probability for dry weight of roots.

A comparison of the nutrition levels, aside from the effect of growth substance, may be made from the controls where no indoleacetic acid was used. The dry weights for the roots indicate no significant differences among the four levels. In regard to dry weight of total plant and tops, however, these four levels differ significantly at 1 per cent probability in all comparisons except that of the 3/9 K with the 9/9 K level. These two are nearly alike in actual weights. During growth



FIGS. 1-6.—Each straight horizontal line represents the value for the specific control treatment which received no growth substance, for comparison with the lots which did. Fig. 1, percentage dry weight of bean tops at four levels of potassium. Fig. 2, dry weights for total plant, top, and root, at 9/9 K level (experiment II). Fig. 3, dry weights for 3/9 K level (experiment II). Fig. 4, dry weights for minus K level (experiment II). Fig. 5, dry weights of total plant at four potassium levels of experiment III. Fig. 6, dry weights for 9/9 K level of experiment IV.

both appeared much the same. Neither showed potassium deficiency symptoms nor any differentiating peculiarities. If based on the control-treatment results, the minus K, 1/18 K, and combined upper two levels seem to constitute the only distinct conditions. Yet a marked difference appears between the 9/9 K and 3/9 K levels in their response to the indoleacetic-acid concentration series (table 1; figs. 2, 3). At 10^{-9} the 9/9 K level yields 12.5 per cent increase in total dry weight over the control at that level, while the same concentration of growth substance with the 3/9 K level is slightly below its corresponding control. The 9/9 K level has a definite curve of response, with 10^{-7} , 10^{-8} , and 10^{-9} concentrations being significant increases and the latter two at 1 per cent probability, while the trend of

TABLE 1

DRY WEIGHT OF TOTAL PLANT, TOP, AND ROOT. FIGURES REPRESENT MEAN WEIGHT IN GRAMS OF SIX SAMPLES OF EIGHT PLANTS EACH

NUTRITION LEVEL AND PLANT PART		INDOLEACETIC-ACID CONCENTRATION								CON- TROL (NO ACID)
		10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}	
9/9 K	Total plant.....	12.50	13.50	14.03*	14.44†	14.49†	13.27	13.35	12.88	
	Top.....	10.70†	11.74	12.32†	12.70†	12.73†	11.68	11.72	11.35	
	Root.....	1.79*	1.76*	1.71	1.74	1.76*	1.59	1.62	1.53	
3/9 K	Total plant.....	13.00	13.26	13.07	13.28	12.76	12.81	13.32	12.99	
	Top.....	10.94	11.40	11.32	11.53	11.21	11.23	11.68	11.35	
	Root.....	2.07†	1.86	1.75	1.75	1.55	1.59	1.64	1.64	
1/18 K	Total plant.....	10.92	10.94	11.91	11.96	11.22	11.63	11.15	11.34	
	Top.....	9.18*	9.29	10.25*	10.16	9.60	9.93	9.58	9.70	
	Root.....	1.74	1.64	1.66	1.79	1.62	1.70	1.57	1.64	
Minus K	Total plant.....	6.48†	9.42	9.80	9.28	9.69	9.69	.....	9.57	
	Top.....	5.24†	7.71	8.14	7.87	8.30	8.14	.....	8.09	
	Root.....	1.24*	1.70	1.66	1.41	1.56	1.55	.....	1.48	

* Significant difference at 5 per cent probability from control at same nutrition level.

† Significant difference at 1 per cent probability from control at same nutrition level.

the 3/9 K level is irregular with no significant points. In this case plants appearing alike but receiving different nutrition responded in a decidedly different manner to indoleacetic-acid applications.

Much the same reaction occurs in relation to dry weight of tops. At 9/9 K significant increases are found at concentrations of 10^{-7} , 10^{-8} , and 10^{-9} , while the 10^{-5} concentration is depressed relative to the control. In the 3/9 K level no point is significant, either above or below the control. Only when root weights are considered does a similarity of response appear. At 10^{-5} concentration, root weights are significantly increased at both levels. A trend for increased root weight with the higher concentrations of indoleacetic acid is indicated.

The 1/18 K and minus K levels exhibited decided potassium deficiency symptoms and differed only in their intensity. Few significant weight differences were obtained at these levels (table 1; fig. 4). The 1/18 K level has significant decrease

at 10^{-5} and increase at 10^{-7} for the tops. On the basis of total plant weight, however, these points are not significant. No definite trend in relation to the indoleacetic-acid concentrations appears at either level. This irregular response does not indicate that indoleacetic acid can replace potassium or lessen the effect of potassium deficiency, as judged by the response of the plant as a whole.

Significant decreases in all three weights at the 10^{-4} treatment provide quantitative evidence for the stunting effect of growth substance under conditions of high concentration. This depression of growth probably would have occurred at any of the nutrition levels with a similar high concentration.

EXPERIMENT III.—To obtain data under growing conditions of higher light intensity, an experiment designed like the one just described but with eight blocks instead of six, and twenty-nine treatments randomized within each block, was carried out between March 17 and April 17, 1941. In this one the minus K level and the 10^{-4} indoleacetic-acid concentration were omitted and an 18/9 K level included. Sixty per cent of the days were sunny, and at noon on clear days light intensity in the greenhouse reached 5500–6000 foot candles. This was indicated in the increased dry weights. For example, the total dry weight of the control plants at the 9/9 K level was 85 per cent greater in this experiment than in experiment II.

Procedure in the two experiments was identical. Ten applications of the various levels of nutrient and growth substance were given. The plants were harvested when the flower buds were well developed, 31 days after planting the seed. Again there were no epinastic curvatures following indoleacetic-acid applications. The pendant position during the day of the primary leaf blades of potassium-deficient plants was observed as the first symptom of such deficiency. Flower buds appeared at the same time on all treatments. The total number of leaves per plant was the same at each nutrition level, regardless of treatment. Noticeable differences were apparent in leaf size and length of stem and petiole. Percentage dry weight decreased with increasing potassium, and the 18/9 K level averaged about 1 per cent lower than the 9/9 K level.

One condition was observed which was not detected in experiment II. On the last days before harvest the primary leaves of many of the 3/9 K level plants showed definite symptoms of potassium deficiency. The environmental conditions resulted in increased growth which apparently brought out the deficiency at this level.

Dry weights of total plant, top, and root were analyzed as before (table 2). Mean differences are significant for dry weight of total plant if greater than 1.46 gm. at 5 per cent probability and 1.93 gm. at 1 per cent probability; for dry weight of top if greater than 0.91 gm. at 5 per cent probability and 1.20 gm. at 1 per cent probability; and for dry weight of root if greater than 0.62 gm. at 5 per cent probability and 0.82 gm. at 1 per cent probability.

Root weights indicate few important differences and no obvious trends relative

to growth substance treatment. The control at 1/18 K is markedly lower than the three higher levels, which cannot be separated among themselves.

Dry weights of tops parallel dry weights of total plant (fig. 5). Consideration of these dry weights of entire plants in the control treatments to observe the effect of the nutrition levels without the growth substance indicates three conditions. The 1/18 K level is significantly lower than the other three. By harvest it exhibited pronounced deficiency symptoms. The 3/9 K level is lower than the 18/9 K level but does not vary significantly from the 9/9 K level. The 3/9 K plants developed the early deficiency symptoms just before harvest. The 9/9 K and the 18/9 K levels cannot be separated on the basis of dry weight of controls.

TABLE 2

DRY WEIGHT OF TOTAL PLANT, TOP, AND ROOT. FIGURES REPRESENT MEAN WEIGHT IN GRAMS OF EIGHT SAMPLES OF EIGHT PLANTS EACH

NUTRITION LEVEL AND PLANT PART		INDOLEACETIC-ACID CONCENTRATION							CONTROL (NO ACID)
		10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}	
18/9 K	Total plant.....	22.14†	.....	24.71	.....	26.13*	.....	24.23	24.62
	Top.....	18.17†	.....	20.47	.....	21.60*	.....	20.04	20.50
	Root.....	3.98	.....	4.24	.....	4.54	.....	4.20	4.12
9/9 K	Total plant.....	21.81†	22.64	23.83	23.70	23.68	23.34	23.58	23.79
	Top.....	17.84†	18.80*	19.97	20.05	19.88	19.73	19.70	19.84
	Root.....	3.97	3.85	3.87	3.66	3.80	3.62	3.87	3.95
3/9 K	Total plant.....	20.44†	21.50	21.80	20.68†	21.16*	21.45	21.05	22.73
	Top.....	16.34†	17.62*	17.93	17.39†	17.51*	17.87	18.05	18.63
	Root.....	4.09	3.88	3.87	3.20*	3.64	3.58	3.90	4.10
1/18 K	Total plant.....	15.26	14.63	14.92	14.70	15.08	14.94	14.80	15.06
	Top.....	12.03	12.05	12.32	11.99	12.41	12.22	12.23	12.28
	Root.....	3.23	2.58	2.60	2.72	2.67	2.71	2.57	2.78

* Significant difference at 5 per cent probability from control at same nutrition level.

† Significant difference at 1 per cent probability from control at same nutrition level.

When the response of the 9/9 K and 18/9 K levels to indoleacetic acid is compared by dry weight of total plant, differences appear. The 18/9 K level yields a significant increase over its control at 10^{-9} concentration and a decrease at 10^{-5} . The 9/9 K trend has only the significant decrease at 10^{-5} . Obviously more potassium was available in the 18/9 K level than in the 9/9 K level during growth of the plants. Although neither showed decided differences in growth of controls, this higher amount of potassium at the 18/9 K level may have been in part responsible for the increase of growth resulting from applications of indoleacetic acid. The two nutrient levels which in experiment II showed little difference in growth of controls and yet different response to indoleacetic acid were the 9/9 K and the 3/9 K. Of these the 9/9 K level yielded the significant increases. Because of much less growth in this test, a similar relationship between potassium supply and plant

growth may have existed in this 9/9 K level as in the 18/9 K level just described. In both cases the dry weight increases correlated with indoleacetic-acid treatment were associated with nutrition levels of relatively high potassium.

The facts that all indoleacetic-acid treatments at the 3/9 K level fall below their control, and that scattered points in this curve are significantly below, suggest that this growth substance may hasten the appearance of potassium deficiency. Symptoms of this deficiency were just beginning to be apparent at harvest, but observations were not recorded on their relative intensity in treated and control plants. No decided differences were obtained between the indoleacetic-acid treatments and control at the 1/18 K level.

TABLE 3

DRY WEIGHT OF TOTAL PLANT, TOP, AND ROOT. FIGURES REPRESENT MEAN WEIGHT IN GRAMS OF SIX SAMPLES OF EIGHT PLANTS EACH.

NUTRITION LEVEL AND PLANT PART		NAPHTHALENE-ACETAMIDE CONCENTRATION						CON- TROL (NO ACETAM- IDE)
		10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}
9/9 K	Total plant.....	7.41†	20.22†	23.06	23.44	24.24	23.83	23.62
	Top.....	3.52†	13.63†	17.92†	18.70	19.36	19.45	19.13
	Root.....	3.89*	6.61†	5.14*	4.74	4.88	4.38	4.49
3/9 K	Total plant.....	7.27†	16.40†	21.93	22.60	21.87	21.83	21.79
	Top.....	3.47†	10.56†	17.00	17.90	17.60	17.55	17.52
	Root.....	3.80	5.84†	4.93	4.72	4.26	4.28	4.22
1/18 K	Total plant.....	6.34†	13.54†	14.75	16.27	15.93	15.30	16.19
	Top.....	3.00†	8.82†	11.50*	12.78	12.52	12.27	12.73
	Root.....	3.34	4.72†	3.25	3.49	3.40	3.03	3.47
Minus K	Total plant.....	5.80†	11.09*	11.63	12.10	12.19	11.75	12.30
	Top.....	3.05†	6.88†	8.84	9.62	9.60	9.39	9.95
	Root.....	2.76	4.22†	2.79	2.48	2.59	2.37	2.35

* Significant difference at 5 per cent probability from control at same nutrition level.

† Significant difference at 1 per cent probability from control at same nutrition level.

ALPHA NAPHTHALENE ACETAMIDE

EXPERIMENT IV.—This experiment was carried out in the greenhouse under similar conditions and at the same time as experiment III. Experiment IV had thirty-one treatments randomized in six blocks, replicated six times. Potassium levels of 9/9 K, 3/9 K, 1/18 K, and minus K were employed, as were acetamide concentrations of 10^{-5} to 10^{-11} (table 3). All plants at the 10^{-5} concentration were much stunted and after eight applications of the nutrients and growth substance had practically ceased growth. The experiment was therefore harvested on the twenty-ninth day after planting.

A pronounced downward curling of the primary leaves at all 10^{-5} concentrations occurred shortly after the first application of naphthalene acetamide. This per-

sisted permanently throughout the experiment, and these plants, regardless of potassium level, remained stunted. Their second internodes elongated little and only one small trifoliate leaf, if any, expanded. Plants at all other concentrations at a given potassium level had the same number of leaves as the control at that level, although there were noticeable reductions in leaf size and stem and petiole elongation at the higher concentrations.

Potassium deficiency in this experiment, as in the others, was first indicated by the pendant position of the primary leaf blades during the day. By the time of harvest chlorosis due to potassium deficiency was evident in the second trifoliate leaves in the minus K plants. Although the flower buds were still extremely small at harvest, there appeared no hastening of their development at this stage by any of the naphthalene-acetamide treatments.

Average dry weights of total plant, top, and root were analyzed (table 3). Differences between means of dry weights greater than 1.14 gm. for total plant, 0.83 gm. for tops, and 0.58 gm. for roots are significant at 5 per cent probability. At 1 per cent probability these mean differences must be greater than 1.50 gm. for total plant, 1.10 gm. for tops, and 0.76 gm. for roots.

The control treatments provide a basis for judging the effect of the four nutrient levels without any naphthalene acetamide. The total plant average weights and averages for tops both differ sufficiently so that each level is clearly separated from the others. The dry weights of roots fall into two groups. The 9/9 K and 3/9 K levels cannot be separated between themselves but they do differ significantly from the 1/18 K and minus K levels, which in turn cannot be separated. Yet the weights for roots decrease consistently with decreasing potassium, so the four levels appear to constitute four distinct nutritional conditions.

Examination of the significant differences between the naphthalene-acetamide treatments and the control at any given level shows that these differences are present only at the higher concentrations. For total plant dry weight they are only decreases, and the same is true for dry weight of tops. The only significant increases in the entire experiment are for dry weight of roots, and these increases are well localized at the 10^{-6} concentrations. At harvest the roots at these treatments were more fibrous and extensive than at others.

The response at any one nutrition level is the same in general trend as that at any other of the four levels tested (fig. 6). The difference appears only in degree, in that the weights are progressively less as potassium supply decreases.

The percentage increase in dry weight of root at the 10^{-6} concentration of naphthalene acetamide over the control at the same level is 47.2 at 9/9 K, 34.3 at 3/9 K, 51.3 at 1/18 K, and 58.6 at minus K. These increases occur in treatments associated with reduction in dry weight of tops. This decidedly alters the ratio of

tops to roots. At the 9/9 K level the dry weight of tops of the control treatment is approximately 4.3 times that of the roots. At the same nutrition level, but with naphthalene acetamide supplied in the nutrient at 10^{-6} concentration, the dry weight of the tops is only 2.1 times that of the roots.

Discussion

When different responses are obtained in nutritional work in which the solutions have been altered by the substitution of a salt, the question arises as to whether the effects are attributable to the altered essential element or to the substituted ion. Such inquiry may well be made in the experiments with indoleacetic acid reported here. The only nutrient level in experiment II which gave significant increases with indoleacetic-acid treatment was that of 9/9 K, which received no sodium after treatments commenced. Perhaps sodium prevented a similar response at the other nutrient levels where it was used as a substitute ion for potassium. But in experiment III, with much greater plant growth, the 9/9 K level failed to give significant increases. Presence of sodium could not have resulted in this response. In this experiment the 18/9 K level, with chlorine as a foreign ion and with higher potassium, did yield a significant increase in dry weight. Yet the increases of experiment II at 9/9 K were obtained on plants watered with solutions containing no chlorine. Sodium and chlorine may influence the response, but it seems unnecessary to consider the absence of sodium or the presence of chlorine of particular importance in obtaining increased growth with indoleacetic-acid applications.

The evidence seems to favor the view that variation in potassium supply rather than variation in the substituted or added ion was chiefly responsible for the different reactions at the several levels. If this is granted, it appears that relatively high potassium is necessary to obtain stimulating effects on growth of the total plant with indoleacetic acid. High potassium plants may be limited in growth by a relative deficit of growth substance. The addition of indoleacetic acid may raise this limitation and increased growth result. At the lower potassium levels this chemical element may be the limiting factor; thus greater supply of indoleacetic acid results in no growth increase.

GRACE (5) has studied the effect of several chemicals used with indoleacetic acid in a talc carrier on the rooting of stem cuttings. He concluded that potassium acid phosphate in combination with indoleacetic acid has decided effects on rooting.

In these experiments, whenever stimulation of total plant dry weight resulted from indoleacetic-acid treatment, it was observed in the same general region of concentrations, 10^{-7} , 10^{-8} , and 10^{-9} . Yet the much different response over the

entire range of concentrations suggests the value of employing several concentrations in experiments with growth substances.

Studies of the response of kidney bean plants to emulsion sprays of naphthalene acetamide have been made by KRAUS and MITCHELL (7) and by MITCHELL and STEWART (10). The latter observed the effects of four concentrations of emulsion spray as judged by dry-weight analysis 10 days after spraying. They reported root increases of 48 per cent with the most concentrated spray. Both papers mentioned the more fibrous nature of the roots and the suppression of top growth with concentrated sprays. These observations are similar to those reported in this paper for the 10^{-6} concentration, although in this work the naphthalene acetamide was applied in the nutrient solution and the plants were not harvested until flower buds were evident. No data were obtained concerning the relative efficiency of the increased root system of plants treated with naphthalene acetamide.

Summary

1. Red kidney bean plants grown in sand culture at different levels of potassium nutrition and receiving indoleacetic acid or alpha naphthalene acetamide in the nutrient solution in a series of concentrations were compared by dry weights of top, of root, and of total plant.

2. Plants receiving different nutrition but externally appearing alike responded in a markedly different manner to indoleacetic-acid treatment.

3. Relatively high potassium in the nutrient solution was necessary to obtain increased dry weight of total plant by indoleacetic-acid treatment.

4. Under certain levels of nutrition, increases as great as 12.5 per cent in total plant dry weight were obtained by indoleacetic acid supplied at the 10^{-9} concentration. Significant increases were obtained at concentrations of 10^{-7} , 10^{-8} , and 10^{-9} .

5. Indoleacetic acid appeared unable either to replace potassium or to enhance its utilization under deficiency conditions, as judged by total plant response.

6. The time of flowering was not hastened by indoleacetic-acid treatment, nor was there any indication that naphthalene acetamide accelerated the appearance of flower buds.

7. The number of leaves per plant was not increased by either growth substance, although leaf size varied considerably.

8. Percentage dry weight increased as potassium decreased, and only at relatively high concentrations of indoleacetic acid (10^{-4}) was increased succulence noted.

9. Plants at four potassium levels yielded the same general trend of response to naphthalene-acetamide treatment. They differed only in the degree of this response, in that dry weights were less with decreasing potassium.

10. Dry weights of roots increased 34-58 per cent at the 10^{-6} concentration of naphthalene acetamide. At this same concentration growth of tops was significantly reduced.

11. The first visible potassium deficiency symptom was expressed by the primary leaf blades retaining the nocturnal pendant position during the day.

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